An Incentive Aware Routing for Selfish Opportunistic Networks: A Game Theoretic Approach

Li Li[1], Yang Qin[1], Xiaoxiong Zhong[1, 2, 3], Hongbin Chen[3]

[1]Key Laboratory of Network Oriented Intelligent Computation, Shenzhen Graduate School, Harbin Institute of Technology, Shenzhen, 518055, P. R. China

[2]Guangxi Key Laboratory of Trusted Software, Guilin University of Electronic Technology, Guilin, 541004, P. R. China

[3]Key Laboratory of Cognitive Radio and Information Processing, (Guilin University of Electronic Technology), Ministry of Education, Guilin, 541004, P. R. China

Email: {lilihitcs, yqinsg, xixzhong}@gmail.com; chbscut@guet.edu.cn

***Abstract*—Many routing schemes in opportunistic networks (OPPNETs) assume that nodes are willing to forward messages to others. However, in practice, nodes in the networks may be selfish due to limited resources or poor social tie. Nodes' selfishness can be classified into individual selfishness and social selfishness. The existing works only consider how to solve the individual selfishness or social selfishness for data transmission respectively. But, the individual selfishness and social selfishness may co-exist in OPPNETs. In this paper, we propose an incentive aware routing for selfish OPPNETs from a game theoretic perspective, which jointly considers individual selfishness and social selfishness to improve the performance of OPPNETs. The scheme maps the message transmission between two nodes as a Rubinstein-Stahl bargaining game, which employs virtual currency and constructs proper price function, considering the nodes resources and the nodes' social ties for data transmission. Trace-driven simulations demonstrate that the effectiveness of the proposed incentive aware routing.**

Keywords—opportunistic networks; incentive routing; game theory; selfishness

I. INTRODUCTION

Opportunistic networks (OPPNETs) [1] are one of the most interesting evolutions of delay tolerant networks (DTNs) and mobile ad hoc networks. In OPPENTs, the nodes transmit messages in a "store-carry-and-forward" manner, using the contact opportunities of the mobile relay nodes.

With the popularization of mobile devices, WiFi and Bluetooth technique, the social-based OPPNETs have been studied by many researchers, in which the mobile carriers communicate with each other to share data among interested mobile users. Hence, many social based routing have been proposed in OPPNETs, which assume that the mobile users are willing to forward messages to the other users. However, in reality, nodes usually adopt selfish behavior in order to save limited resources or protect their private information. There are two forms of selfishness: individual selfishness and social selfishness [2]. Nodes with individual selfishness have the same degree of selfishness toward all other nodes, while nodes with social selfishness prefer to provide services to others based on their social relationships.

In order to solve these two types of selfishness in the OPPNETs, several routing schemes have been proposed to stimulate selfish nodes for cooperation. For the individual selfishness, consider the significant damage caused by selfish nodes, Shevade et al. [3] proposed an incentive aware routing for DTNs, which exploits pair-wise tit for tat (TFT) mechanism for DTNs. Wu et al. [4] proposed a game-theoretic approach based on bargaining to incentive selfish nodes for cooperation in probabilistic routing over OPPNETS. Zhu et al [5] proposed a secure multilayer credit-based incentive (SMART) scheme for DTNs with selfish nodes. In 2016, Cai et al. [6] presented an efficient incentive compatible routing protocol (ICRP) with multiple copies for two hop DTNs based on game theory and optimal sequential stopping rule.

Social selfishness will also affect node behaviors. A node will not forward messages to the nodes which has no social ties with the currently node, and prefer some nodes with stronger ties. These can be reflected by willingness of nodes. By considering the social ties among nodes, there are some works consider to incentive the social selfishness for cooperation [2, 7]. Taking individual selfishness and social selfishness into account, Sermpezis et al. [8] proposed a novel framework for analyzing node cooperation in data transmission of OPPNETs from a social features and mobility patterns perspective.

The existing works mainly consider how to solve the individual selfishness or social selfishness for data dissemination respectively, only Ref. [8] jointly considers them to improve the performance of the OPPNETs. However, in [8], the authors only evaluate the effects of social selfishness on the performance of OPPNETs and present an analytical framework for it. They did not use incentive to stimulate selfish nodes to cooperation for enhancing the performance of OPPNETs, ignoring comprehensive utilization of node's encounter status, which have a significant impact on the performance of data transmission in OPPNETs.

Motivated by these observations, in this paper, we present a novel Incentive-Aware Routing from a Game Theoretic perspective, IAR-GT, for selfish OPPNETs, which joint considers individual selfishness and social selfishness to improve network performance. The contributions of our work can be summarized as follows.

- We give a novel method to calculate social ties between two nodes according to the history information of the node contact and social similarity.

- We map the message transmission between two nodes as a Rubinstein-Stahl bargain game, and construct price function for the two nodes, which not only consider node's residual resources and virtual currency, but also consider the social ties of two nodes, and the message time-to-live (TTL).
- We evaluate the performance of our incentive scheme with reality trace. Through the evaluation, we validate the effectiveness of the proposed incentive routing scheme in selfish OPPNETs.

II. SYSTEM MODEL

In this paper, we map the message trade between two nodes as a Rubinstein-Stahl bargain game [9]. We assume that the node carried the message be defined as the buyer, denoted by *B*; the relay node which can help to forward the message be defined as the seller, denoted by *S*; the buyer may want to buy the relay node's service. Because nodes in the networks are selfishness, both of players usually like to maximize their benefits. Hence, we assume that each node possesses some kinds of virtual money, and we properly stimulate nodes to cooperate by exploiting the virtual money payment mode.

To enable nodes to pay and manage the virtual currency, we assume that there is a Credit Clearance Center (CCC) [4]. Each node should firstly register itself to the CCC and obtain its account. When it forwards the message, it will hold a digitally signed receipt and submit the receipt to the CCC. After the destination receives the message and sends ACK to CCC, the relay nodes will obtain a certain number of virtual money in return. And the relay nodes have enough virtual money also can pay for the other nodes which forwarded their messages.

III. INCENTIVE AWARE ROUTING

In this section, we analyze the factors affected nodes selfishness and then propose an incentive aware routing from a game theoretic perspective.

A. Factors affected nodes selfishness

Because the nodes are rational, they will be selfish due to limited resources and poor social ties. The estimated residual resource of nodes is a factor to affect nodes selfishness. We denote the total buffer space and the energy of node *i* as S_i and E_i. The residual buffer space and energy of node *i* at time *t* can be defined as $r_i^S(t)$ and $r_i^E(t)$ respectively. Hence, the estimated residual resource utilization ratio of node *i* at time *t* can be calculated:

$$R_i(t) = \frac{\omega_1 r_i^S(t)}{S_i} + \frac{\omega_2 r_i^E(t)}{E_i} \tag{1}$$

where ω_1 and ω_2 are the weights, constrained by $\omega_1 + \omega_2 = 1$.

Furthermore, because our paper is designed for social-based OPPNETs, nodes may appear some social selfishness due to different social ties. In this paper, we characterize the nodes' social ties according to the history information, such as contact frequency, their contact duration, the contact regularity, and the social similarity of nodes. Hence, the social ties between currently node *i* and relay node *j* can be reflected by the following formula.

$$ST_{i,j} = \frac{1}{\varphi SPM_{i\,j} + (1-\varphi) socsim_{i,j}} \tag{2}$$

where φ ($\in [0,1]$) is the weight factor, $SPM_{i,j}$ is the social pressure metric of node *i* and node *j* [10], and $socsim_{i,j}$ is the social similarity between node *i* and node *j*.

$SPM_{i,j}$ can reflect three behavioral features of close friendship: high frequency, regularity, and longevity, which is computed as follows

$$SPM_{i,j} = \frac{\int_{t=0}^{T} f(t)dt}{T} \tag{3}$$

where $f(t)$ returns the remaining time to the first encounter of these nodes after time *t*, and *T* is the time interval.

$socsim_{i,j}$ is the social similarity between node *i* and node *j*, which can be calculated :

$$socsim_{i,j} = \frac{com_{i,j}}{n_i + n_j} \tag{4}$$

where n_i is the number of neighbor nodes for node *i*, n_j is the number of neighbor nodes for node *j*, and $com_{i,j}$ is the number of common neighbors between *i* and *j*.

B. Incentive Aware Routing Scheme

In the following, we define the utility function of bargaining game and describe the incentive aware routing.

(1) Incentive Scheme based on Rubinstein-Stahl bargain game

In the Rubinstein-Stahl bargain game, the buyer and the seller can make offer alternative. We first define the price of two players.

For the buyer B, it wants to buy the service of the seller S for a message with minimum price. First, the buyer should consider message influence for the price, such as the message size, message residual *TTL*. Second, the buyer should consider node's residual resource and virtual money possessed, these factors also impact for the price. Hence, for the message *m*, the buyer's price at time *t* can be expressed as

$$pr_{B,m}(t) = L_{(m)} \times C_B(t) \times \left(\frac{1}{\rho_1 R_B(t) + \rho_2 T_{B,m}(t)}\right) \tag{5}$$

where $L_{(m)}$ is the size of message *m*, $C_B(t)$ is the virtual currency that the buyer B has at time *t*, $R_B(t)$ is the ratio of residual resource of buyer B at time *t*, ρ_1 and ρ_2 are the weight factors satisfying $\rho_1 + \rho_2 = 1$, and $T_{B,m}(t)$ is the ratio of residual TTL of message m at time t for buyer B, which is computed as

$$T_{B,m}(t) = \frac{r_{B,m}^{TTL}(t)}{TTL_m} \tag{6}$$

where $r_{B,m}^{TTL}(t)$ is the residual TTL of message m at time t for buyer B, and TTL_m is the TTL of message m.

Similarly, for the seller S, it can provide the service to the seller S for a message with maximum price. It should also consider the relationship between it and the buyer node except the above factors. Hence, the seller's price can be expressed as

$$pr_{S,m}(t) = L_{(m)} \times \frac{1}{ST_{S,B}} \times C_S(t) \times \frac{1}{R_S(t)} \tag{7}$$

where $ST_{S,B}$ is a factor that reflect the social ties between buyer B and seller S, $C_S(t)$ is the virtual currency that the seller B has at time t, $R_S(t)$ is the ratio of residual resource of seller S at time t. For different social ties, the nodes will give different price.

In the bargaining game, the buyer and the seller make offer $pr_{B,m}(t)$ and $pr_{S,m}(t)$ respectively. If $pr_{B,m}(t) < pr_{S,m}(t)$, the transaction will failure; Only when $pr_{B,m}(t) > pr_{S,m}(t)$, two players may reach an agreement. And the difference $pr_{B,m}(t) - pr_{S,m}(t)$ will be the total profits. We define this difference as the "cake" in the Rubinstein-Stahl bargain game. Hence, the "cake" size (total profits) for the message m at time t can be expressed as

$$Val_m(t) = pr_{B,m}(t) - pr_{S,m}(t) \tag{8}$$

The buyer and seller will bargain over the division of the total profits (cake). The set of the possible agreement is

$$X = \{(x_S, x_B) \in \mathbb{R}^2 : x_S \geq 0, x_B \geq 0, x_S + x_B = 1\} \tag{9}$$

where x_S and x_B are the proportion of the cake divided for seller and the buyer sides respectively.

Further, because the seller and the buyer are selfish, they try to maximize their benefits, that is, they want to obtain as much proportion of the cake as possible. Hence, the utility function of buyer and seller for message m can be defined as

$$u_{S,m}(x_S) = x_S Val_m,\ u_{B,m}(x_B) = x_B Val_m \tag{10}$$

The Rubinstein-Stahl bargaining game may run many rounds, however, the cost and the time may be waste in each round when the bargain game carry out. The buyer and seller sides have their own patience, which is named the discount factor. The factor can reflect two player's benefit that are decreased with the time, such as, the cake will melts with increasing of the bargain time, so, the benefit of each player will decrease when the round increases. We use δ_S and δ_B to denote the discount factor of seller and buyer respectively.

Hence, the utility function of players can be calculated:

$$\begin{aligned} u_{S,m}(x_S) &= \delta_S x_S Val_m \\ u_{B,m}(x_B) &= \delta_B x_B Val_m \end{aligned} \tag{11}$$

In the Rubinstein-Stahl bargain game, the patience can affect the bargaining process of both seller and buyer. If the buyer has enough resources and virtual currency, and the message's TTL is also longer, it will have more patience in the bargaining game, and want to obtain more proportion of the "cake". Moreover, the patience factor is from zero to one. The conditions for patience functions of buyer are defined as

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$$\begin{aligned} &\frac{d\delta_B(C_B(t) * R_B(t) * T_{B,m})}{d(C_B(t) * R_B(t) * T_{B,m})} > 0, \\ &\delta_B(0) = 0,\ \delta_B(\infty) = 1 \end{aligned} \tag{12}$$

Any functions that satisfy (12) can be selected as patience functions of buyer B. We employ the following function [12] for the patience of buyer B

$$\delta_B(x) = \frac{e^{\lambda x} - e^{-\lambda x}}{e^{\lambda x} + e^{-\lambda x}} \tag{13}$$

where λ is the patience coefficient of the buyer.

For the seller S, it wants to forward more messages from different nodes to earn more virtual currency. Hence, it lacks patience in bargaining. Moreover, the social ties of two players also affect the patience of seller. The patience is from one to zero. Therefore, the conditions for patience functions of seller are defines as

$$\begin{aligned} &\frac{d\delta_S(ST_{S,B} * C_S(t) * R_S(t))}{d(ST_{S,B} * C_S(t) * R_S(t))} < 0, \\ &\delta_S(0) = 1,\quad \delta_S(\infty) = 0 \end{aligned} \tag{14}$$

The following function [12] can be employed as the patience function of seller S

$$\delta_S(x) = 1 - \frac{e^{\mu x} - e^{-\mu x}}{e^{\mu x} + e^{-\mu x}} \tag{15}$$

结果是如何计算得到的？

where μ is the patience coefficient of the seller.

In Rubinstein-Stahl model, there exists a unique *subgame perfect Nash Equilibrium* for the bargaining game. After several rounds of bargaining, both sides will finally come to an agreement. And this final agreement will be obtained.

$$(x_B^*, x_S^*) = \left(\frac{1-\delta_S}{1-\delta_B\delta_S}, \frac{\delta_B(1-\delta_S)}{1-\delta_B\delta_S} \right) \tag{16}$$

Our incentive aware model is a complete information bargaining game, and the final results of game can be calculated in both players by exchanged patience factors. Therefore, the real bargaining process between two selfish nodes is not necessary so as to decrease the overhead as well as excessive workload of the bargaining process.

(2) Forwarding Scheme

In this subsection, we will introduce the message forwarding process of incentive aware routing. Due to the nodes in the networks are selfish, hence, we employ multiple-copy routing with limited copies so as to increase the successful delivery ratio and save networks resources. When the source wants to send message m to its destination D, the source creates limited m's copies and forwards one copy to its meeting relay node j using incentive scheme. And then, the relay node j forwards the copy to its meeting node with higher predictability, using incentive scheme, and deletes the copy. Next, we will take forwarding processes between two nodes as an example to describe the incentive forwarding scheme in detail.

In the beginning of game, the node i sends the requesting information to node j, these information includes message ID, the message size, the buyer's price according to (5), and the patience factor (14). The relay node j receives the requesting information, it will firstly determine the relationship between i and j, and computes the social ties between two nodes according to (2). Then, node j calculates its reserve price for transmitting message m according to its resources and virtual currency. If the seller j's price is higher than that of the buyer's, the bargaining game will be over, and the message m will not be forwarded. Otherwise, these two players i and j will obtained benefits from this trade according to (8) and (10), relay node j calculates the value (x_S^*, x_B^*) and $u_{S,m}(x_S^*)$, and then, sends acknowledgement packet and piggybacks its reserve price and its patience factor to node i. The node i determines whether the utility $u_{B,m}(x_B^*)$ is positive, if so, node i will forward the message m to node j, otherwise, the game will be over.

When two sides i and j complete the transaction, they will get a digitally signed receipt for this transaction. Nodes will submit this receipt to the CCC. If the destination receives the message m, it will send an ACK to the CCC when it connects the Internet. According to the digitally signed receipts, each relay node can obtain virtual currency for the transaction.

IV. PERFORMANCE EVALUATION

We evaluate the performance of the proposed incentive aware routing scheme in Opportunistic Network Environment simulator (ONE) [13]. We use MIT reality data traces [14] to evaluate the performance of incentive-aware routing, which consists of the traces of 97 Nokia 6600 smart phones. These smart phones were carried by students and staff at MIT over 9 months. The 78 mobile iMotes were deployed, which have a wireless range around 10m. Moreover, there are the 20 stationary (long range, around 100m) iMotes in the network. In our simulations, we generated 2857 messages during 342915s.

In the simulation, each node from a random source node to a random destination node. The message size is 100k-500k randomly, the message creation interval is 120 seconds, and the TTL of the message is 1440 min. The weight factors of resources ω_1 and ω_2 are 0.45 and 0.55, respectively. We set $\varphi = 0.5$, $\rho_1 = 0.6$, $\rho_2 = 0.4$, and patience coefficient $\lambda = \mu = 0.6$. Moreover, the bandwidth is 2 Mbps, and the node's buffer size is set to 15M. Since the reality data trace does not have the accurate social relationship information among participants, we need to construct a weighted directed social graph upon them. We refer the method of [15], but it only considers the contact frequency, we modify them according to (2).

We compare IAR-GT with Epidemic [18], dlifeComm [19], Spray-and-Wait (SNW) [20], and ICRP [5], to demonstrate the performance of routing in term of delivery ratio, average delay, overhead, and an artificial metric-delivery ratio × (1 / average delay) × goodput [16. 17]. Moreover, in the simulation, the number of replicas for SNW, ICRP, and IAR-GT are set to 8.

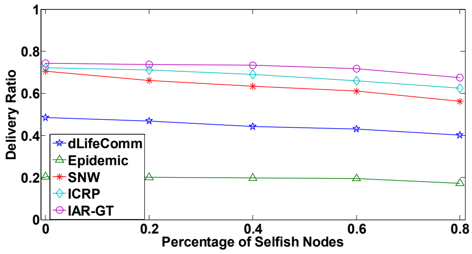

Fig.1 Delivery ratio vs. percentage of selfish nodes

From Fig.1 we know that the delivery ratio of all protocols will decline with increasing of the percentage of selfish nodes. No-incentive routing protocols (Epidemic, dLifeComm, and SNW) achieve lower delivery ratio than that of the incentive aware routing (ICRP, IAR-GT). IAR-GT has the highest delivery ratio. This is because it considers two kinds of selfishness, and then efficiently incentive more selfish nodes for cooperation. Moreover, the IAR-GT can effectively control message replicas, which can save the limited resources. Although ICRP is also an incentive-compatible routing for selfish nodes, it has a smaller delivery ratio. This is because it does not consider the social ties among selfish nodes, which can efficiently promote selfish nodes to cooperation.

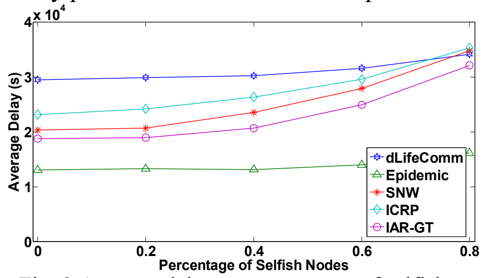

Fig. 2 Average delay vs. percentage of selfish nodes

Fig. 2 reflects the average delay of five protocols with increasing of the percentage of selfish nodes. With increasing of percentage of selfish nodes, the average delay of all schemes will increase, but Epidemic and dLifeComm increases smoothly. Epidemic has the smallest delay. This is because Epidemic floods messages to all neighbor nodes, hence, the messages have more chance and be quickly delivered to the destination. IAR-GT achieves a smaller delay than the other three schemes. This is because IAR-GT exploits bargaining game which considers many factors to incent nodes' selfish behaviors, and efficiently employs social ties among nodes, so as to relay messages more quickly to their destination.

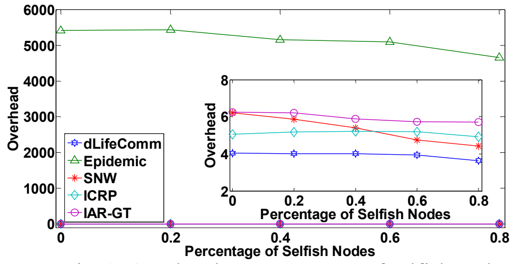

Fig. 3 Overhead vs. percentage of selfish nodes

Fig. 3 presents the overhead of five protocols. Epidemic is a flooding-based routing. When nodes are selfish with limited resources, the packet loss of Epidemic is very serious, and its overhead is far larger than the others. In order to clearly display the overhead of other 4 protocols, we use the subfigure to show the comparison results. From the subfigure, we know that the overhead of IAR-GT is slightly higher than that of ICRP and SNW. This is because IAR-GT scheme can efficiently incent more selfish nodes to participate forwarding, so as to increase the successful delivery ratio and reduce delivery delay, but relays more messages. ICRP employs two-hop manner to forward. Source forwards a message at most two hops to arrive at its destination. SNW sprays fixed number of message will fall into "Wait" stage. Hence, their overhead is smaller than that of IAR-GT.

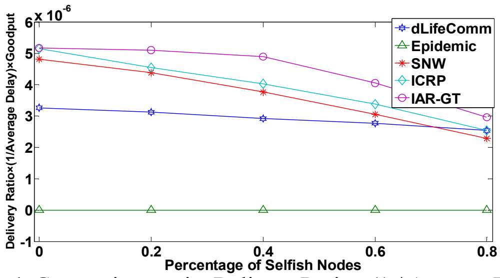

Fig. 4 Composite metric: Delivery Ratio× (1 / Average Delay) × Goodput vs. percentage of selfish nodes

Fig. 4 reflects the simulation results of routing protocols in terms of composite metric: Delivery Ratio × (1 / Average Delay) × Goodput, which can reflect the overall performance of the protocols. Although the overhead of our scheme IAR-GT is not the smallest in all protocols, as shown in Fig. 3, we can seen that the proposed scheme IAR-GT can achieve the best overall performance than other protocols, as shown in Fig. 4.

V. CONCLUSION

In this paper, we propose a game theoretic incentive aware routing, IAR-GT, for selfish OPPNETs, which jointly considers individual selfishness and social selfishness for improving the performance of selfish OPPNETs. IAR-GT incorporates the proposed data forwarding scheme that considers the node's resource utilization and the node's social ties for data dissemination. The simulation results show that using the proposed routing scheme can achieve better performance. In future work, we will continue to examine the efficiency of incentive aware routing scheme in high-speed mobility and reliable communication scenario.

ACKNOWLEDGMENT

This work was supported by the Science and Technology Fundament Research Fund of Shenzhen under grant JCYJ20140417172417131, the Natural Science Foundation of Guangdong Province under grant 2014A030313698, GUET UF16008Y, and by the National Natural Science Foundation of China (Grant Nos. 61671165, 61602125).

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